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CHAPTER 4.12
INTERNALLY GROUND PARTS

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THE PROCESS

Essentially, internal grinding removes material from the inside of a hole. Generally, the part is caused to revolve about the desired axis of the hole, and a grinding wheel that revolves about its own axis is placed inside the hole and fed radially to contact the part. If size or external shape makes rotation of the part about the hole axis impractical, the part is kept stationary, and the grinding wheel is given a planetary motion about the hole axis in addition to its rotation about its own axis, as in a jig grinder. Figure 4.12.1 illustrates a typical internal grinding machine.

Hole-size control is often accomplished by *diamond sizing,* feeding the wheel at a fixed distance from where it was when it was last dressed by the relatively fixed diamond.

Profiles are usually dressed directly into the wheel and then reproduced in the part by a purely radial feed. A true spherical profile is usually generated directly with the corner of a cylindrical wheel whose axis intersects the axis of revolution of the part. Profiles that are longer than a practical wheel length are produced by moving a shorter barrel-shaped wheel along the required path by means of a template or a CNC program. Profiles are dressed into wheels by profiled diamond rolls or by mechanisms that use pivots, templates, or a CNC program to impart the required path to a single-point diamond.

TYPICAL CHARACTERISTICS OF INTERNALLY GROUND PARTS

Characteristics Likely to Require Internal Grinding

The most frequent reason for internal grinding is that the part material is too hard to be machined economically by a nonabrasive process and must be machined after hardening to correct heat-treatment distortion and to remove scale or decarburized material.

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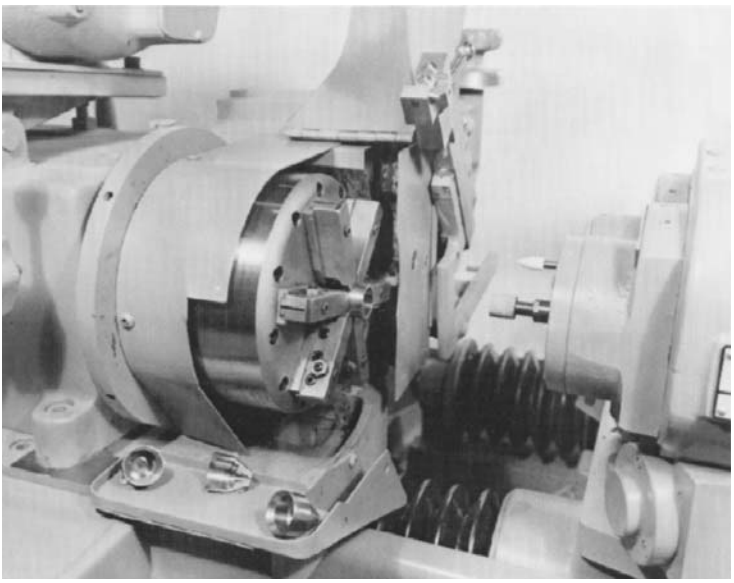

FIGURE 4.12.1 Internal grinding machine with an outside-diameter clamping diaphragm chuck and two wheel spindles. (*Courtesy Bryant Grinder Corporation.*)

Other frequent material-related reasons are that materials are too fragile for other processes, are smeared by other processes (electric-motor or synchro lamination stacks, porous bearings), or are too abrasive for economical tool life (some filled plastics.)

Thin walls either all around or partway around parts or interruptions such as splines or cross holes often dictate an abrasive process rather than a cutting process. A complex surface form with a tight form tolerance often can be ground most economically because of the ease with which the grinding-wheel form can be restored by the dresser as compared with the difficulty of maintaining the form with either a form tool or a template-guided tool. Because a grinding wheel has its cutting surface continually renewed by dressing, and because it can remove very small and closely controlled amounts of stock, internal grinding can be more economical than precision boring when tolerances fall below 0.013 mm (0.0005 in) on size, 0.0025 mm (0.0001 in) on roundness, and 0.5 μm (20 μin) on surface finish.

Characteristics that Influence the Choice between Internal Grinding and Honing

Some of the above-mentioned characteristics also make honing a suitable or even a preferred process. (For more details, see Chap. 4.16.) A brief review of the strengths and weaknesses of both processes follows. Internal grinding becomes difficult when hole length exceeds 1200 mm (48 in) or 6 times the hole diameter, whereas such lengths present no problem to honing. Internal production grinding is practical for hole diameters from 2 m (80 in) to 1 mm (0.040 in), although toolroom work occa-

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sionally has gone a little smaller; honing normally is not used over 1-m (40-in) or under 6-mm (0.25-in) diameter. Both processes are used with interruptions such as splines or cross holes, but honing has less tendency to round over their corners or to remove too much material in their vicinity. Both processes are suitable for blind holes, but internal grinding can reach closer to the blind end. Honing requires a 6- to 9-mm- ($\frac{1}{4}$- to $\frac{3}{8}$-in-) long relief, whereas grinding is practical with 0.8 mm (0.030-in) relief or can produce a 0.25-mm (0.010-in) corner radius, although a 3-mm- ($\frac{1}{8}$-in-) long relief is preferred.

Although both processes can produce fine surface finishes, grinding is generally practical only down to finishes of 0.13 to 0.2 μm (5 to 8 μin) AA, whereas honing continues to be practical down to 0.05 μm (2 μin) or less. However, only grinding can produce precise location and orientation of the hole axis with respect to other surfaces, although both processes can produce excellent roundness and straightness.

Typical Parts and Materials

Internally ground holes may be cylindrical or conical, have faces or shoulders inside the hole, and have a noncircular cross section as in a vane pump ring, or have an axial profile as in a gun chamber or ball-bearing track.

The following list shows the range of reasonably common applications of internal grinding; inner-ring bores and outer-ring tracks of ball and roller bearings, bores and inside faces of universal-joint needle-bearing cups, bores of automotive hydraulic-valve-lifter bodies, bores and tapered seats of fuel-injection-nozzle bodies, bores and external faces of gear or gear clusters, bores of connecting rods, bores of valve rocker arms, noncircular bores of hydraulic-vane pumps or refrigeration compressors, internal and external spheres of ball joints and axial-piston-pump slippers, internal spheres of constant-velocity universal-joint cages and outer races, bores of drill bushings, bearing sleeves, bores and faces of machine-tool spindles and metal or ceramic magnets or cores, contoured bores of gun chambers and wire-drawing dies, and tapered-joint bores of glass plumbing. Most parts fall within a hole-diameter range of 1 to 100 mm (0.040 to 4 in), but many fall between 100 and 500 mm (4 and 20 in), and some reach 80 in in diameter. Materials are usually through-hardened or case-hardened wrought steels but include cast steels, nitrided steels, stainless steels, cast iron, soft magnetic-lamination iron, bronze, aluminum, the various tungsten and titanium carbides, titanium, Alnico, ferrite, graphite, ceramics, glass, and glass- or mineral-filled plastics. Figures 4.12.2 and 4.12.3 illustrate typical internally ground parts.

ECONOMIC PRODUCTION QUANTITIES

Since there usually are no large initial costs for such items as dies or molds, there usually is no minimum lot size below which internal grinding would be uneconomical. Therefore, quantities as small as one piece are suitable for internal grinding. At the other extreme, production of thousands of parts per hour for many years also may be economic. Lot size and desired production rate do influence the decision between acquiring machinery and subcontracting to the possessor of machinery or between acquiring manually operated machinery and acquiring fully automatic machinery.

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FIGURE 4.12.2 Typical internally ground parts. The internal surfaces of these parts are routinely ground despite thin walls, interruptions, and special contoured cross sections. (*Courtesy Bryant Grinder Corporation.*)

FIGURE 4.12.3 Typical internally ground parts. (*Courtesy Bryant Grinder Corporation.*)

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Exceptions, in which initial costs might be significant, are cases requiring a formed diamond-dressing roll, an axial-profile template, or a cross-section-contour cam. If production quantities justify it, even usual jobs will benefit from initial investment in optimal part-holding and -locating tooling and perhaps in a costly diamond or cubic boron nitride grinding wheel if the material is difficult to grind.

For truly high production quantities, as with automotive-bearing parts, handling is fully automatic at rates between 100 and 600 parts per hour per machine on machines requiring one operator for every 3 to 7 machines and one setup person for every 10 to 20 machines. On such machines, changeover tooling is required for each additional part within a family; changeover time ranges between 10 and 60 min if the tooling is preset and grinding-cycle adjustments are made to prerecorded settings.

SUITABLE MATERIALS

A combination of materials such as inserts, welds, solders, or adhesives interspersed with the main material may add to grinding time by requiring frequent dressing of the wheel if there is no compromise wheel that neither wears too rapidly when in contact with the harder material nor clogs too rapidly when in contact with the softer material. Chromium plating combined with hardened steel is a fine choice. Copper or cadmium plating with hardened steel can cause problems, as can soft-steel inserts in or a decarburized layer on hardened steel and some plastic fillers in motor lamination stack slots. For similar reasons, part design should allow inexpensive removal of such materials as soft black scale and paint from internal surfaces that are to be ground.

Sometimes compromise is necessary; e.g., air-hardening steels have good dimensional stability but are more resistant to stock removal than the less stable oil- or water-hardening steels.

Hardened alloy steels become increasingly difficult to grind with increasing hardness of the carbide or the carbide-forming alloying element, i.e., from chromium to molybdenum to tungsten to vanadium. An increasing percentage of carbide and therefore of alloying elements (if sufficient carbon is assumed to be present) also means increasing difficulty. Within any one alloy, increasing R_c hardness also increases grinding difficulty. However, increasing nickel content only slightly increases grinding difficulty. Soft and ductile materials may require very little force, but they do require a wheel that wears rapidly in order to prevent a buildup of part material in the pores of the wheel.

Some soft materials, e.g., austenitic stainless steels, are tricky to grind because they act soft during heavy cuts but work-harden severely during light cuts. The free-machining characteristics of resulfurized steels also tend to benefit grinding, but such benefits are less clearly indicated with leaded steels, which may even have such a nonuniform lead distribution as to cause localized excess lead concentrations to load the wheel. Through-hardened steels distort less than surface-hardened steels, though they grow more, but growth is not a problem because the amount is small and somewhat predictable. Tempering does provide some stress relieving or equalization and, combined with proper quenching techniques and fixtures, can do much to minimize distortion.

Specific grindability values for materials suitable for internal grinding can be found in Chap. 4.15, “Flat-Ground Surfaces,” since flat surface and internal grindability are closely parallel.

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DESIGN RECOMMENDATIONS

Standardization

When a product has a number of internally ground components, the designer should strive for maximum part quantity by standardizing on one part design in place of two or more different designs whenever this would achieve an economy while still satisfying all functional requirements. When parts cannot be identical, much can be gained by designing them to be members of a family with as many common characteristics as possible. This procedure usually will permit consideration of the total family volume when justifying investment in some degree of automation of the process, and it will minimize the amount of setup or changeover time.

Holding, Locating, and Driving Surfaces

Parts that are to be held in a chuck must present surfaces to the gripping portions of the chuck and to the locating portions of either the chuck or the chuck-loading fixture. Thin-walled parts will show a greater influence of outside-diameter quality on inside-diameter quality. Face-clamping chucks are more forgiving of outside-diameter quality but require better face flatness to prevent a misshapen inside diameter unless either the inside diameter is very short or the part is very rigid.

If the part is magnetically driven for internal centerless grinding, the end face of the part must provide sufficient area for good magnetic holding. An area equal to 25 percent of the area to be ground internally usually will be sufficient.

Length of Hole to Be Ground

Deep, narrow holes necessitate the use of less rigid spindles or quills. These increase grinding time and the possibility of waviness and chatter. A rule of thumb is to avoid hole length-to-diameter ratios in excess of 6. The problem is less severe as diameter increases and more severe as material grindabiity decreases. The rule applies to the reach distance to the hole as well as to the ground portion, as shown in Fig. 4.12.4.

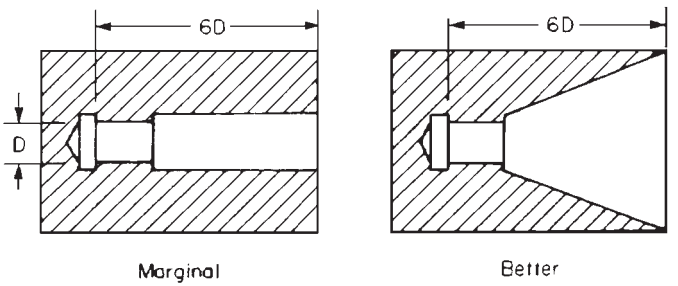

FIGURE 4.12.4 Holes deeper than 6 times diameter and with overly long-reach distances to the ground hole should be avoided unless the area is wide enough to provide rigid support for the wheel spindle.

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Blind Holes

Grinding may take longer for a blind hole because the flow of coolant in the region of contact between the wheel and the part may be marginal, forcing a reduction in the infeed rate, and the flow may be nonuniform, making it more difficult to keep straightness and taper within tolerance. When necessary, however, a blind hole is practical, provided a sharp corner is not required at the blind end. While a corner radius of 0.25 mm (0.010 in) is possible, a previously machined corner relief or neck is better. If the desired profile is a straight line, a relief of at least 3-mm ($\frac{1}{8}$-in) axial length will minimize straightness and taper problems by permitting sufficient reciprocation of the wheel to correct minor deviations. (See Fig. 4.12.5.)

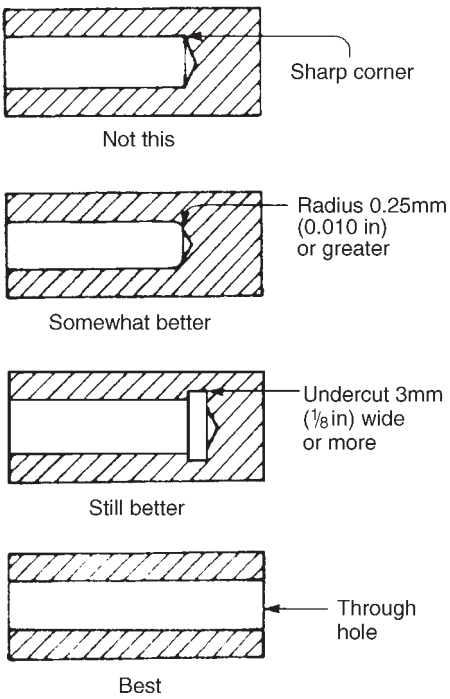

FIGURE 4.12.5 Treatment of blind holes.

Circumferential Interruptions

These interruptions should be avoided if possible. The less rigid the quill or spindle, the greater the tendency of the wheel to remove more stock in the vicinity of a cross hole or to round the corners of a keyway or spline slightly. When such deviations would exceed the tolerance, they usually can be reduced at the cost of longer grinding time by reducing the infeed rate and lengthening spark-out time.

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Axial Interruptions

Similarly to the circumferential case, a reciprocating wheel has a tendency to remove more stock near an interruption in the axial line of contact such as a circumferential valve groove or a relief. In contrast to outside-diameter grinding, it is usually best not to put a relief in the middle of a long inside diameter even if only the ends of the inside diameter are to be used. If the part material shows reasonable grindability with the wheel being used, axial interruptions will incur a grinding-time penalty only when the hole diameter is less than 2 in and at the same time the hole length-to-diameter ratio exceeds 3. This effect is usually negligible with plunge grinding (no reciprocation).

Amount of Stock

Although not directly specified by the designer, the amount of stock is often the result of design decisions. Table 4.12.1 presents suggested stock allowances for internal grinding. Since many variables, such as type of material and heat treatment, quality of previous operations, and rigidity of the internal-grinding setup, will affect the minimum amount of stock required, some experimenting is worthwhile if the production quantity is high. Table 4.12.1 can be used to find a starting point. Careful design and process planning may permit leaving less stock than shown in the table.

Use of a Liner or Insert

In some cases, problems related to material, locating surfaces, or length of reach can be eliminated by grinding a liner that is later pressed into or otherwise made integral with the less-suitable actual part. The advantages must be weighed against the cost of an extra part and the effects of tolerance buildup. Chromium plating and flame or plasma spraying are other approaches to be considered.

Internal Faces

If possible, leave a relief (the larger the better) in the center of an internal face. One reason for having the relief is to facilitate coolant flow into the contact zone. Another is to permit the use of a cupped wheel rather than a wheel with nearly full end-face contact and to permit this cupped wheel to have a diameter greater than one-half the part-face diameter. Nearly full wheel–end-face contact does not grind well because of poor coolant access and low wheel surface speed near the wheel center. A cupped wheel grinds much better but will leave an unground region in the center of the face unless the rim of the cup passes through the center. (See Fig. 4.12.6.)

Hole with Confined Entrance

The entrance must be large enough to pass a reasonable wheel size and avoid interference with the quill or spindle even after the wheel has worn somewhat. (See Fig. 4.12.7.)

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TABLE 4.12.1 Suggested Stock to Be Left for Internal Grinding*

Diameter of hole, in	Length of hole, in													
	5/16	1/2	3/4	1	1 1/2	2	2 1/2	3	3 1/2	4	5	6	7	8
1/8	0.004 0.005	0.004 0.005												
1/4	0.005 0.006	0.005 0.006	0.006 0.008	0.006 0.008										
1/2	0.005	0.005	0.006	0.006	0.008	0.008	0.006	0.006	0.008	0.008	0.010	0.010		
3/4	0.006 0.008	0.006 0.008	0.008 0.010	0.008 0.010	0.010 0.012	0.010 0.012	0.010 0.012	0.010 0.012						
1	0.008 0.010	0.008 0.010	0.008 0.010	0.008 0.010	0.010 0.012	0.010 0.012	0.010 0.012	0.010 0.012	0.010 0.012	0.010 0.012				
1 1/2	0.008 0.010	0.008 0.010	0.010 0.012	0.010 0.012	0.010 0.012	0.012 0.015	0.012 0.015	0.012 0.015	0.012 0.015	0.012 0.015	0.012 0.015			
2	0.010 0.012	0.010 0.012	0.010 0.012	0.012 0.015	0.012 0.015	0.012 0.015	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	
2 1/2	0.012 0.015	0.012 0.015	0.012 0.015	0.012 0.015	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020
3	0.012 0.015	0.012 0.015	0.012 0.015	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020
4	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.018 0.020	0.018 0.020	0.018 0.020	0.018 0.020	0.020 0.025	0.020 0.025	0.020 0.025	0.020 0.025	0.020 0.025

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TABLE 4.12.1 Suggested Stock to Be Left for Internal Grinding* (*Continued*)

Diameter of hole, in	Length of hole, in													
	5/16	1/2	3/4	1	1 1/2	2	2 1/2	3	3 1/2	4	5	6	7	8
5	0.018	0.018	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025
	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030
6	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030
	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.035	0.035
7	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.035	0.035	0.035	0.035	0.035
8	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.035	0.035	0.035	0.035	0.035

*Under average conditions and rigid wall thickness; for hardened steel. Stock is given for diameter of hole and excludes runout of hole due to improper centralization of work in fixture.

Source: From *The ABC of Internal Grinding,* Norton Company, Worcester, Mass., 1961.

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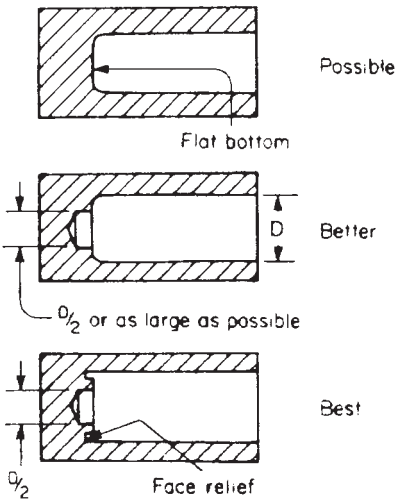

FIGURE 4.12.6 Flat-ground bottoms should be avoided. Center relief of one-half the hole diameter or more avoids the need to grind in the center area, where the grinding wheel's surface speed is low. Relief at the outer corner also helps provide flatness.

Access for Coolant

Because a rapidly spinning internal-grinding wheel is a very effective "flinger" type of centrifugal seal, coolant is unlikely to work its way into the grinding contact zone against the centrifugal action of the wheel. Either an axial through flow or a nozzle aimed at that portion of the wheel outside diameter which is about to enter the contact zone must be allowed by the part design. (On sufficiently large blind parts, a through flow has been accomplished by introducing the coolant through a hollow wheel spindle.)

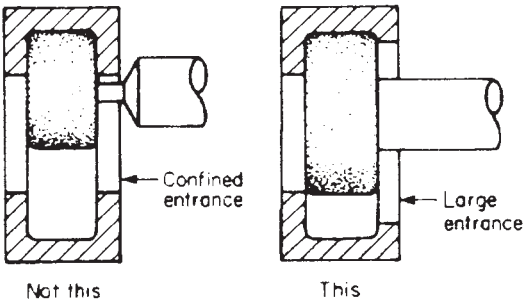

FIGURE 4.12.7 Hole with confined entrance.

DIMENSIONAL FACTORS

There are definite limitations to the degrees of perfection that are practical for the various dimensional attributes of internally ground surfaces. Important factors are whether or not the machine is in good condition, whether the ways are straight, and whether the axis of the wheel, the axis of the part, and the contact point of the dresser are coplanar.

Any one internally ground surface will be subject to tolerances on some of the following attributes: roundness, straightness, taper (these three sometimes combined as cylindricity), concentricity, squareness, size, location in various directions, surface fin-

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ish, surface waviness, axial profile, and cross-sectional contour, all of which affect cost.

Since the grinding wheel and the quill or spindle of an internal grinder must be slender and long enough to reach into the hole, their rigidity can be limited. This limitation distinguishes internal grinding from all other grinding processes. Severely diminished rigidity causes the wheel to tend to follow the existing surface rather than to generate a new, true surface. This makes it more difficult to control hole size and taper. In extreme cases, it can cause an unacceptable amount of waviness or chatter in the ground surface as a result of wheel unbalance or self-excited vibration between the wheel and the part. Another factor is the limited number of abrasive grains in contact with the work when a small internal-grinding wheel is used. This causes greater wheel wear and necessitates more frequent dressing. Both of these conditions are accentuated if materials of low grindability are used.

The roundness of centerless internally ground surfaces depends largely on the roundness of the outside diameter of the workpiece. The accuracy of form internal grinding depends on the accuracy of the form of the wheel as well as on the other factors indicated above. Similarly, the profile accuracy of nonround holes depends on the accuracy of the mechanism which controls the position of the grinding wheel.

Factors affecting surface finish in internal grinding are parallel to those involved in other grinding methods. (See Chap. 4.15.)

TOLERANCE RECOMMENDATIONS

Recommendations in this subsection are based in part on standards of the antifriction-bearing industry. Table 4.12.2 presents recommendations for tolerances on hole diameters. These tolerances include allowances for the effect of taper and roundness deviations.

Surface finishes between 0.4 and 0.8 μm (15 and 30 μin) AA are normal for internal grinding. Allowing a surface finish coarser than 0.8 μm (30 μin) AA rarely will produce cost savings. A surface finish below 0.4 μm (15 μin) AA is likely to lengthen grinding time significantly, although finishes as fine as 0.13 μm (5 μin) often can be obtained.

Squareness of bores and faces or shoulders ground in one placement of the workpiece can be held within 0.00025 to 0.00063 mm (0.000010 to 0.000025 in) TIR (total indicator runout). If operations are performed separately, a squareness tolerance of 0.005 mm (0.0002 in) TIR is recommended. The same tolerances can be applied to parallelism specifications.

TABLE 4.12.2 Recommended Tolerances for Internally Ground Holes

Hole diameter, mm (in)	Normal tolerance, mm (in)	Tightest tolerance, mm (in)
0–25 (0–1)	±0.004 (±0.00015)	±0.0013 (±0.00005)
25–50 (1–2)	±0.005 (±0.0002)	±0.0013 (±0.00005)
50–100 (2–4)	±0.008 (±0.0003)	±0.0025 (±0.0001)
100–200 (4–8)	±0.013 (±0.0005)	±0.0032 (±0.00013)
200–400 (8–16)	±0.020 (±0.0008)	±0.005 (±0.0002)

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Concentricity tolerances with chucking grinders can be as low as 0.0025 mm (0.0001 in) TIR, but 0.013 mm (0.0005 in) TIR is preferable if it can be tolerated for both chucking and centerless machines.

Roundness deviations normally can be held within 0.0025 mm (0.0001 in) on radius, and 0.00025 mm (0.000010 in) is not unusual.

Location in the axial direction can readily be held within ± 0.013 mm (0.0005 in) and with extra care and favorable conditions to 0.0013 mm (0.00005 in).

Cross-sectional contours are customarily allowed to deviate by 0.025 mm (0.001 in) on either side of the perfect contour, but some are held to 0.005 mm (0.0002 in).

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